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Art Unit	3711
Examiner Name	Hunter, Alvin A.
Attorney Docket Number	02RSC064

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- ☐ Fee Transmittal Form
  - ☐ Fee Attached
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- ☐ Proprietary Information
- ☐ Status Letter
- ☑ Other Enclosure(s) (please Identify below):

Letter providing a copy of an article on friction processing techniques as background material.

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	Rockwell Scientific		
Signature			
Printed name	David Zoetewey		
Date	12/16/05	Reg. No.	45,258

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	Mahoney	Examiner:	HUNTER, Alvin A.
Serial No.	10/673,613	Art Unit:	3711
Filing Date:	09/29/2003	Docket No.	02RSC064
Title:	Enhanced Golf Club Performance via Friction Stir Processing		
Subject:	Background article on friction stir processing		
Addressee:	COMMISSIONER FOR PATENTS P.O. Box 1450 Alexandria , Virginia 22313-1450		

14 December 2005

Sir:

Enclosed is an article that provides some information on the distinctions between friction processing technologies. It is provided in hopes that it will help in understanding the difference between friction stir welding and friction stir processing as discussed in the recently filed response.

Respectfully submitted,

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FRICTION Processing Technologies

1999

Friction is an efficient thermo-mechanical source to both weld and process materials. Benefits include refined microstructures, no porosity, little distortion, and the ability to join a wide range of dissimilar materials.

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TWI
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Friction, which requires relative motion, applied pressure, and time, is a powerful, efficient energy source for welding and reprocessing of materials. Friction-based technologies may be divided into three major categories: rotary welding, non-rotary welding, and friction processing.

Rotary friction welding has been around for about fifty years, and is still the most widely used of the friction technologies. In this process, one cylindrical shape is rotated against a similar fixed component under pressure. The material at the faying surfaces becomes plasticized, and the parts are forged together. Taper-stud, taper-stitch, plunge, and third-body welding are variants on this technology. In 1991, a major advance was made in the technology when friction stir welding was developed at TWI. It differs from conventional rotary technology in that a hard, nonconsumable, cylindrical tool causes the friction.

Non-rotary welding was another major advance. Linear, orbital, and angular reciprocating motions permit the joining of noncircular shapes such as squares and rectangular bars, which are very difficult to weld with rotary technology to provide correct alignment.

Friction processing involves the application of friction and pressure to consolidate or refine the microstructure of a material. In friction extrusion technology, a consumable bar is plasticized and pressed through an orifice to improve mechanical properties. In friction co-extrusion, a sheath of uniform thickness may be clad around the core extruded bar. For powder consolidation, the powder materials are plasticized and extruded.

The table identifies the multitude of friction-based processes that are now available for commercial exploitation. This article outlines rotary friction welding, describes friction stir welding in some detail, and gives two examples of friction processing of metals. Future articles will provide more complete explanations of selected friction processes.

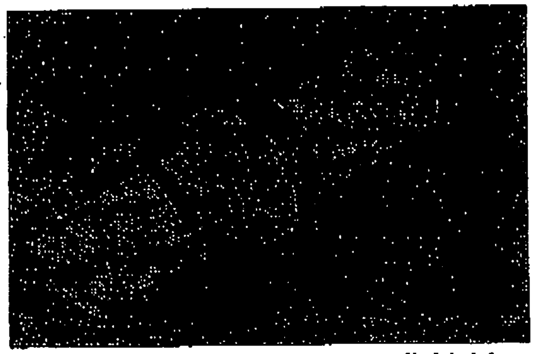

Fig. 1 — In rotary friction welding, one cylindrical shape is rotated under pressure against a stationary part.

Rotary friction welding

The most common form of friction welding is rotary friction welding (Fig. 1), which accounts for most of the friction welding machines in industry. These machines are capable of welding solid bars from about 1 to 200 mm (0.04 to 8 in.) in diameter, and tubes of larger diameter. The biggest machine is based on the stored energy variant, and can deliver 2000 tons axial thrust. Industries that currently manufacture parts with this technology include offshore (drill pipe and underwater stud), petrochemical, electrical, hydraulics, power generation, and railway. The nuclear, aerospace, automotive, machine tool, and wire drawing industries also exploit this technology.

Continual development of rotary friction welding has led to smaller, lighter machines, which enables them to be brought to the construction site. Therefore, manufacturers now have the capability to repair equipment in hostile environments such as under water, in high radiation conditions, and in explosive atmospheres. Specific rotary welding technologies for such applications include friction [redacted]

Friction processes

Rotary drive friction welding	Linear, angular friction welding
Friction stir welding	Friction surfacing
Friction co-extrusion cladding	Friction seam welding
Friction taper stitch welding	Orbital friction welding
Friction plunge welding	Friction transformation hardening
Friction hydropillar processing	Friction extrusion
Radial friction welding	Friction brazing
Third-body friction welding	

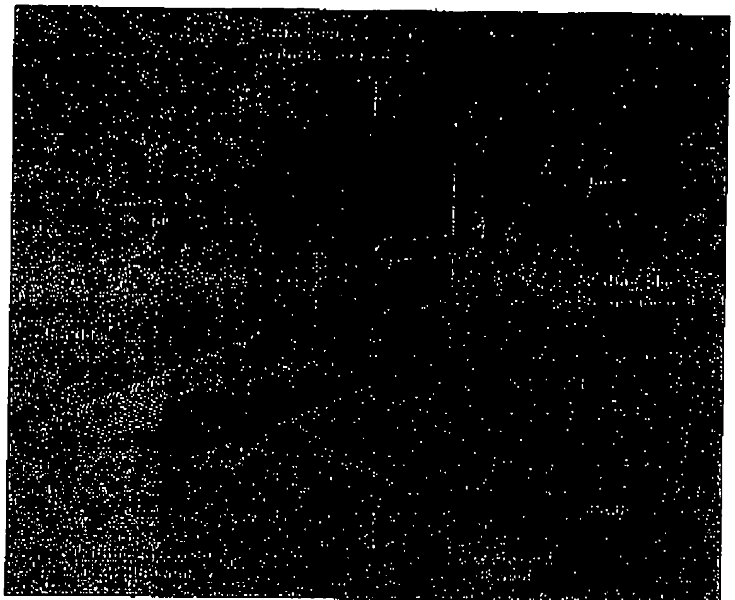

Fig. 2 — Friction stir welding is a thermomechanical hot shear process in which metals are welded in the solid state. Materials joined by the technology include aluminum alloys, aluminum-matrix composites, steel, lead, magnesium, zinc, and copper.

Friction stir welding is a thermo-mechanical hot shear process.

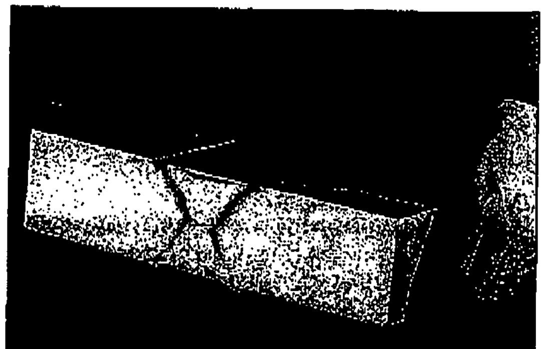

Fig. 3 — This 75 mm (3 in.) thick plate of aluminum alloy 6082 was friction stir welded with two passes.

stud, friction hydropillar processing, and friction taper stitch welding.

Friction stir welding

Friction stir welding (Fig. 2) is a thermomechanical hot shear process in which a non-consumable tool is inserted and rotated within a joint. A rotating, shouldered probe tool with a probe length slightly less than the weld depth required, is inserted into the faying faces until the tool shoulder is in intimate contact with the work surface. The cylindrical tool is made from a material that is hard and wear-resistant relative to the material being welded. The rotating probe moves within the workpiece, heating the metal by friction, and the yield strength of the material at the interface between the rotating tool and the workpiece falls below the applied shear stress. As the probe is moved in the direction of welding, the leading edge of the probe, assisted by a special probe profile, forces the plasticized material to the back of the probe. A plasticized tubular shaft of metal then forms around the probe. At the same time, a consolidating force is applied to the plasticized material. The result is a high-integrity weld made in the solid phase, with no macro. melting.

No filler material or shielding gas is required friction stir welding, and no current or voltage controls are needed. The process is more tolerant to fit-up variations than variable polarity plasma arc fusion welds, and it results in low residual stress and distortion and a fine, hot-worked microstructure. Mechanical properties are improved, with higher joint strength (~70% joint efficiency), higher joint weld ductility, improved fatigue life, and higher fracture toughness. In addition, the process has some tolerance to imperfect weld preparation: thin oxide layers can be accepted.

The process, which was invented, patented, and developed by TWI, is similar in some respects to both laser and electron beam welding, in that a keyhole is developed. It is a derivative of friction welding, which enables the advantages of solid phase welding to be applied to the fabrication of long butt and lap joints with very little post-weld distortion. Moreover, it is a simple-to-operate, very cost-effective machine tool technology offering many advantages.

The joining of aluminum alloys, especially those that are often difficult to weld, was the initial target for developing and judging the performance of friction stir welding. Work initially was concentrated on single pass welds in material thickness from 1.6 to 12.7 mm (0.06 to 0.5 in.). Further developments within this process have demonstrated that plate thicknesses of aluminum alloy 6082 up to 75 mm (3 in.) thick can be welded in two passes (Fig. 3). In addition, a low-carbon, 12% chromium steel plate 25 mm (1 in.) thick and 1 m (3 ft) long has been friction stir welded at TWI. Metal matrix composites may be welded by this technique, as well as other metals such as copper, lead, titanium, and magnesium, although more studies are needed for titanium and its alloys.

Thermal energy is obviously required to soften the material being welded to enable plastic flow into the keyhole behind the tool. Unfortunately, when welding work-hardened (5000 series) and heat-treated aluminum alloys, thermally affected regions do form, where both proof stress and ultimate tensile strength are adversely affected. This limitation has prompted workers in the FSW field to seek solutions to minimize these effects. For example, Threadgill, Howes, and Thomas of TWI have and are continuing to evaluate the influence of heat extraction by water-cooled fixtures, backing bars with high thermal conductivity, and enforced cooling at the weld surface. An extreme example of enforced cooling is to actually make the weld while it is totally submerged in water — it does work!

Preliminary results when welding an aluminum alloy 7075 specimen that is nominally 6 mm (0.24 in.) thick, showed that the proof stress and ultimate tensile strength were increased by 25% and 6% compared with the same welds made without enhanced thermal extraction. Other approaches have involved cooling of the welding tool itself. One advantage of this approach, apart from improving weld quality, is to increase tool life.

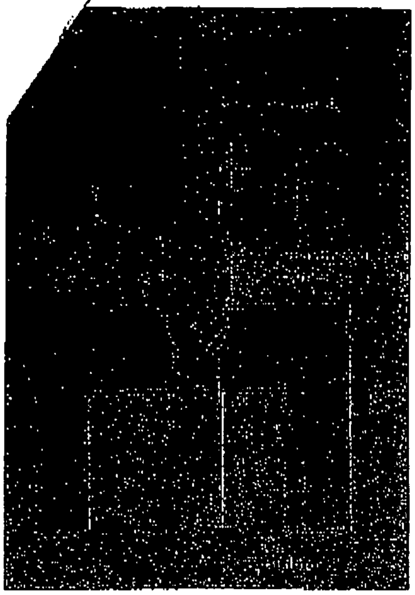

Fig. 4 — During friction extrusion, a high shear strain rate is developed at the boundary between the die and the consumable bar. The bar is rotated, pressed against a die, and extruded through the die orifice.

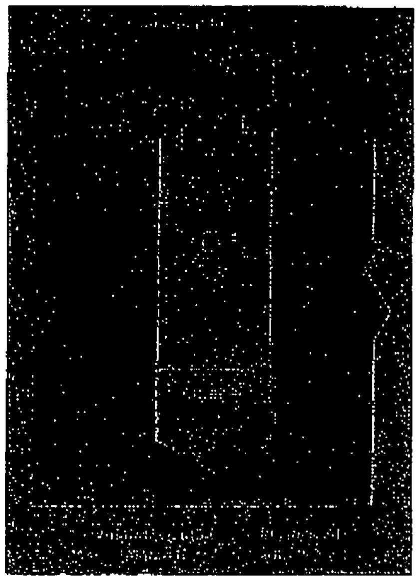

Fig. 5 — Friction pillar processing refines the microstructure of cast bars.

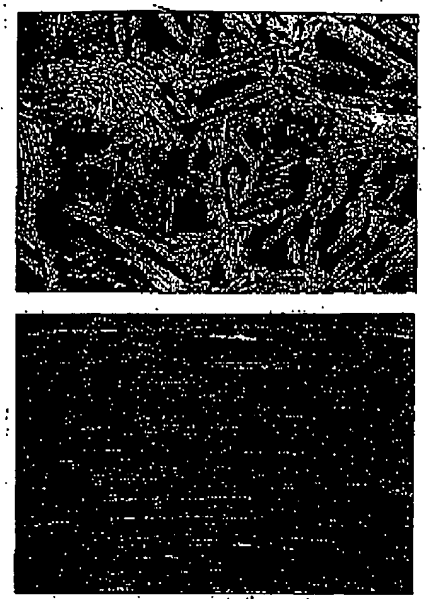

Fig. 6 — The photomicrograph at top shows an as-cast nickel-aluminum-bronze alloy bar magnified 100 times. The bottom photomicrograph shows the same bar after reprocessing by friction pillar processing.

Friction processing

Friction processing can be designed to recycle swarf, make new alloys (monolithic and composite), or reprocess existing alloys to improve metallurgical and mechanical properties. Such processes include friction extrusion, friction pillar processing, and friction transformation hardening.

Friction extrusion (Fig. 4) is an alternative extrusion process in which the required temperature is generated and maintained by friction contact between the consumable and the extrusion dies. During the process, a high shear strain rate is developed at the boundary between the die and the consumable, and within the plastic zones of the consumable. A consumable bar is rotated, pressed against a die, and extruded through the die orifice.

The ensuing temperature rise can lead to deformation at localized regions. Since material softens locally, further deformation is concentrated within this region, and under an axial load it is continuously extruded through the open ended die. The process is suitable for consolidation and re-forming of previously formed metal matrix composite material. The process causes any discontinuities or inhomogeneities in the composite to be redistributed as the material passes through the plasticized zone.

Friction pillar processing (FPP) is shown in Fig. 5. In this technology, a cast material may be processed to improve its microstructure. The consumable bar is rotated under an applied load, which causes a softened layer to form across the rotational interface. The plasticized material develops faster than the feed rate of the feedstock, causing the frictional interface to rise along the feedstock. The softened material is extensively worked during the processing operation, causing refinement of the microstructure and elimination of casting defects such as porosity or hot cracks. Figure 6 shows cast specimens of nickel-aluminum-bronze that have been processed by FPP. The as-cast microstructure has been completely eliminated and replaced by a fully dense, fine grained, and heavily worked microstructure. ■

Friction processing can be designed to make new alloys or reprocess existing alloys.

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